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(54) **IMAGE GENERATION DEVICE, IMAGE DISPLAY SYSTEM, AND INFORMATION PRESENTATION METHOD**

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A63F 13/537	(2006.01)
G06F 3/01	(2006.01)
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(57) **ABSTRACT**

Disclosed herein is an image generation device including: a space construction section that constructs a virtual world to be displayed on a head-mounted display; an image generation section that generates, based on a position and a posture of a head of a player wearing the head-mounted display, a display image representing the virtual world in a field of view corresponding to a point of view of the player, and causes the head-mounted display to display the generated display image; and a visitor information acquisition section that acquires information regarding presence of a visitor without a head-mounted display in a space where the player is able to move. While the visitor is present, the space construction section displays an object indicating the presence of the visitor at a corresponding position in the virtual world.

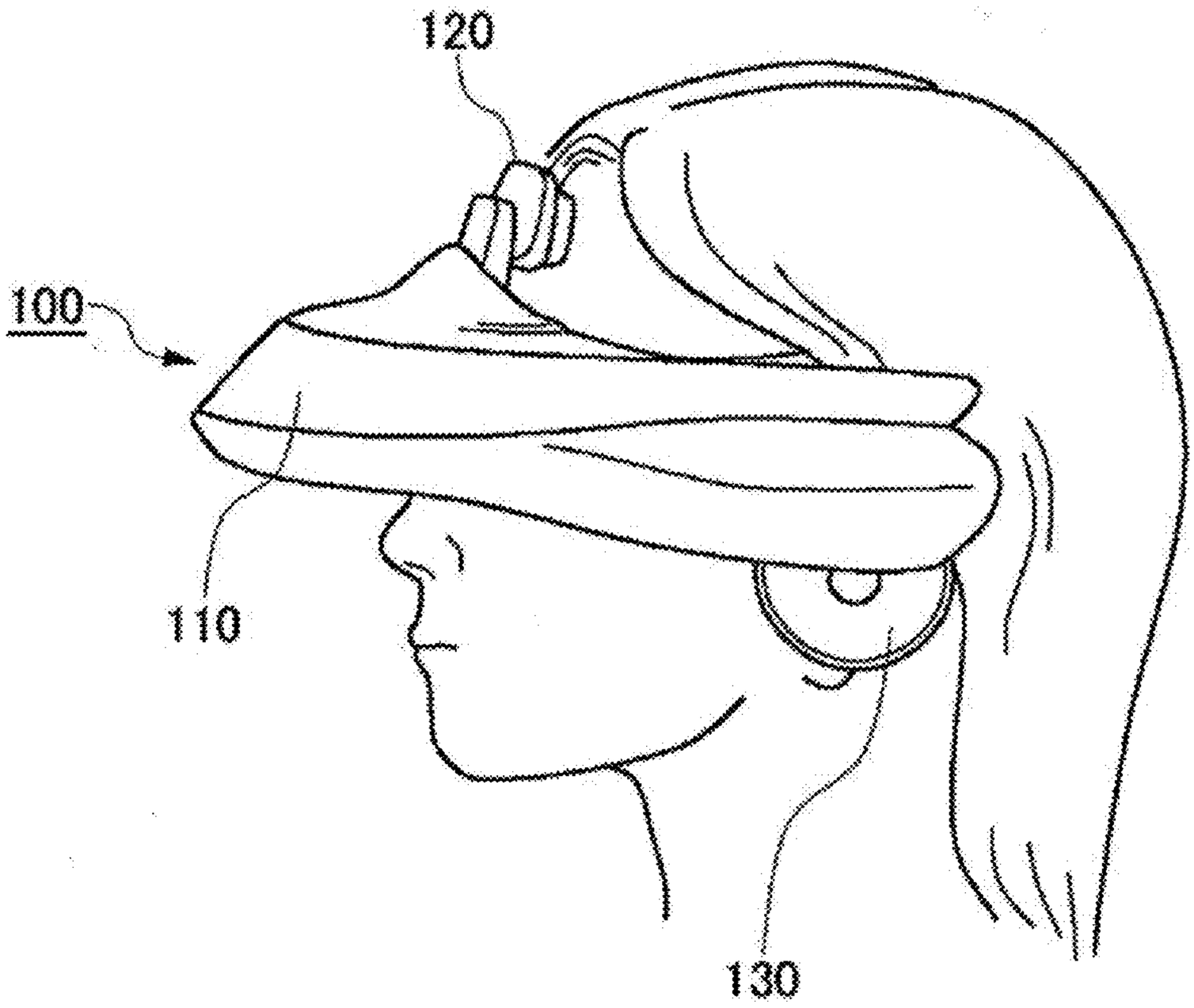


FIG. 1

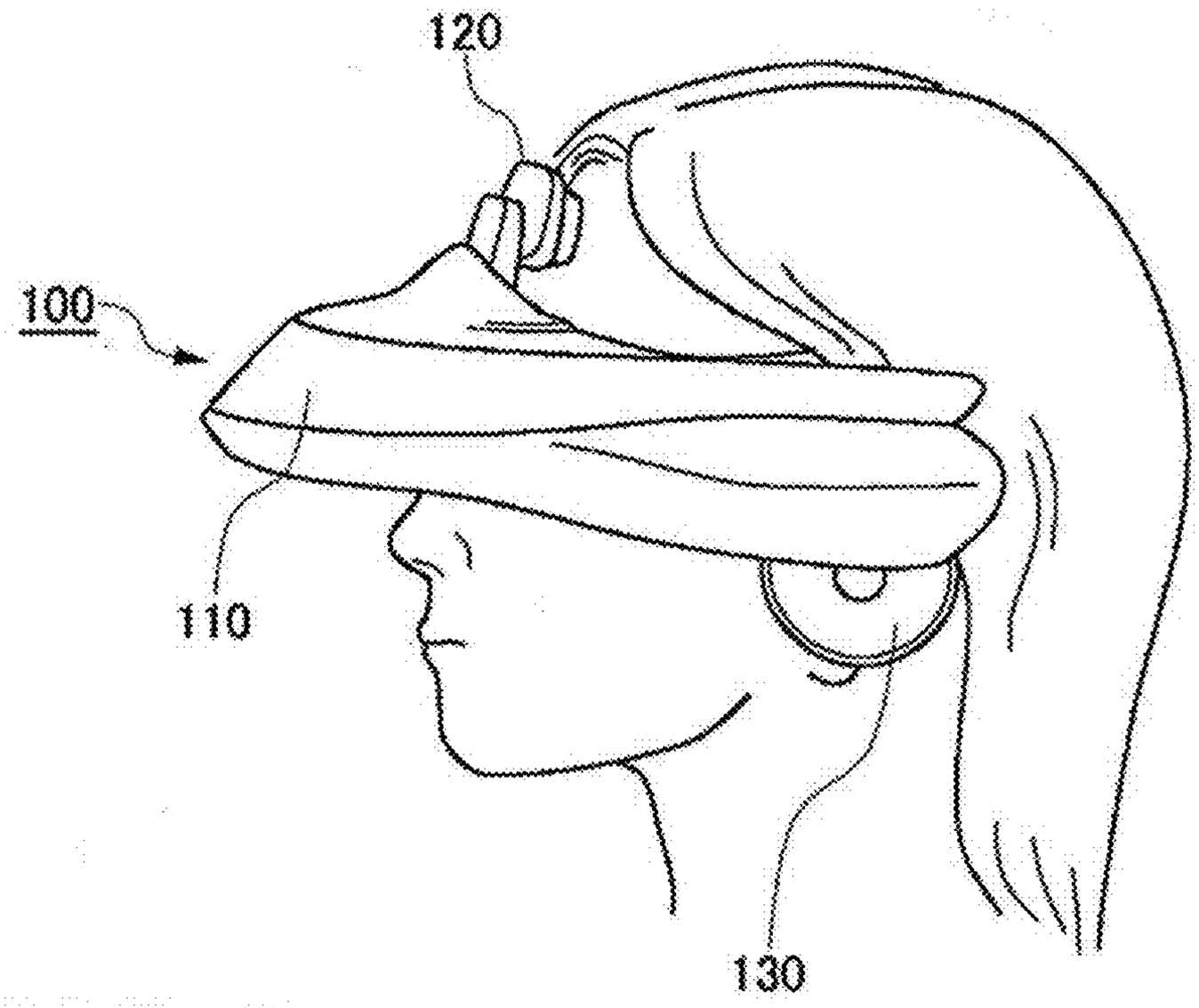


FIG. 2

FIG. 3

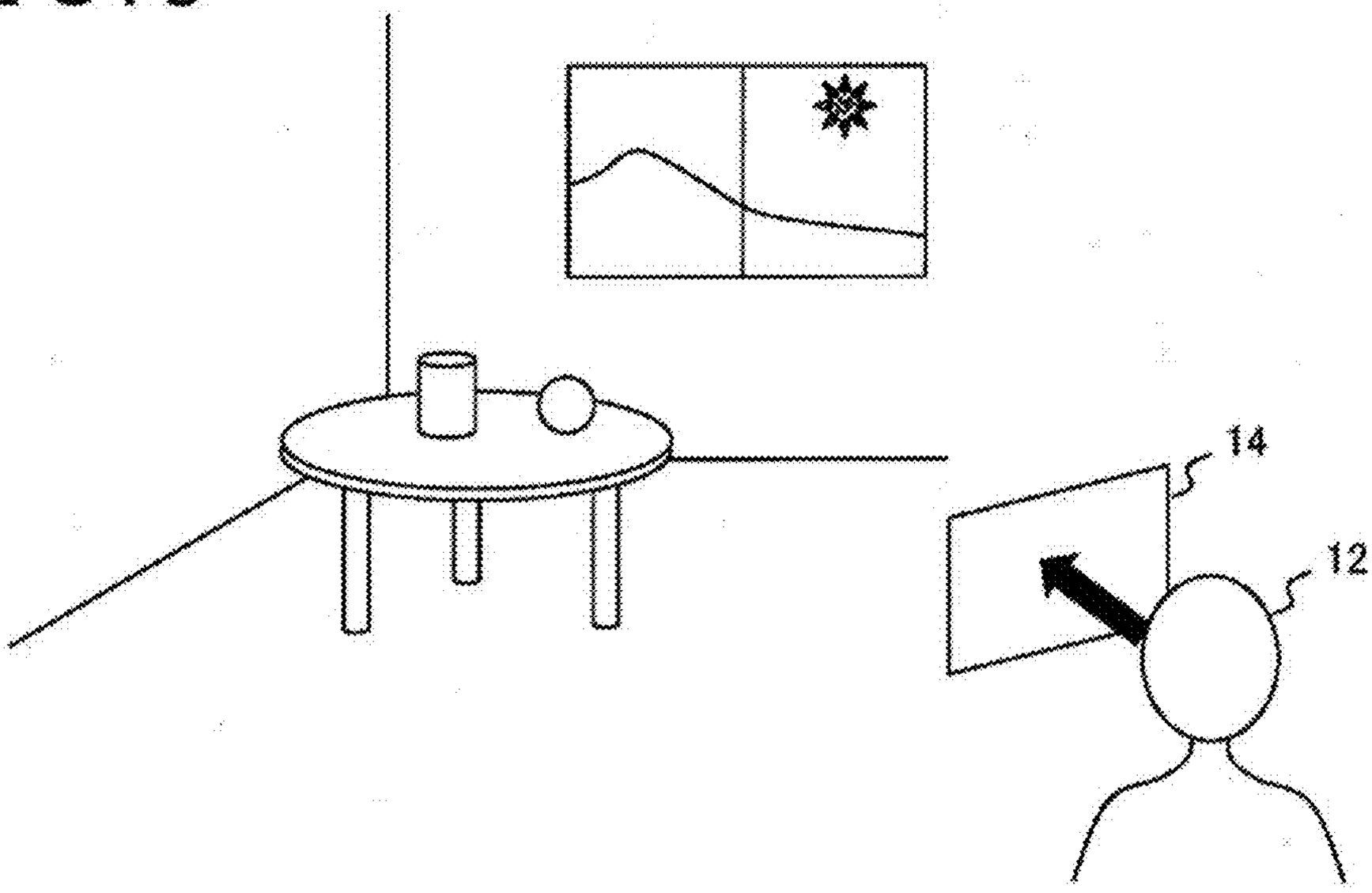
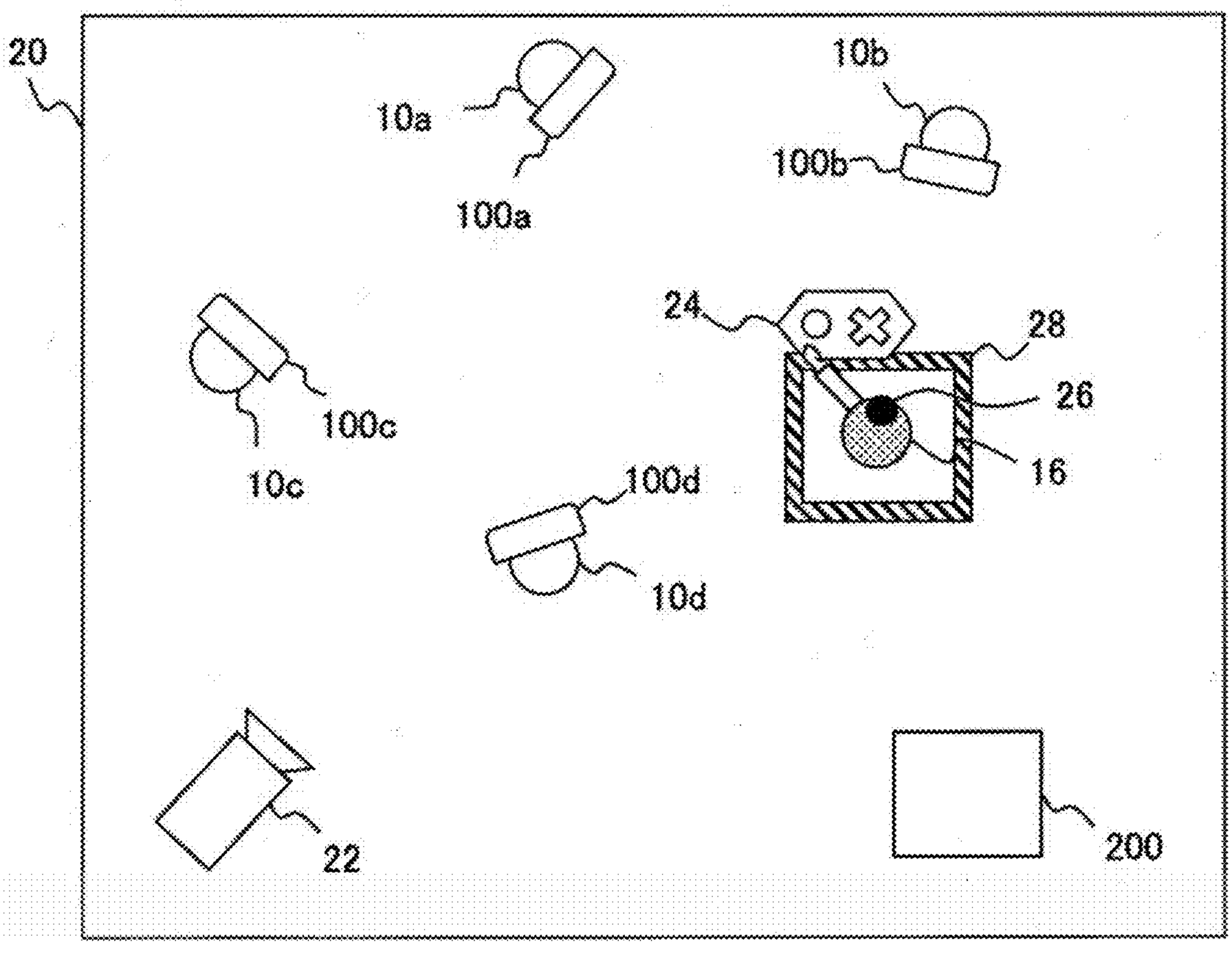


FIG. 4



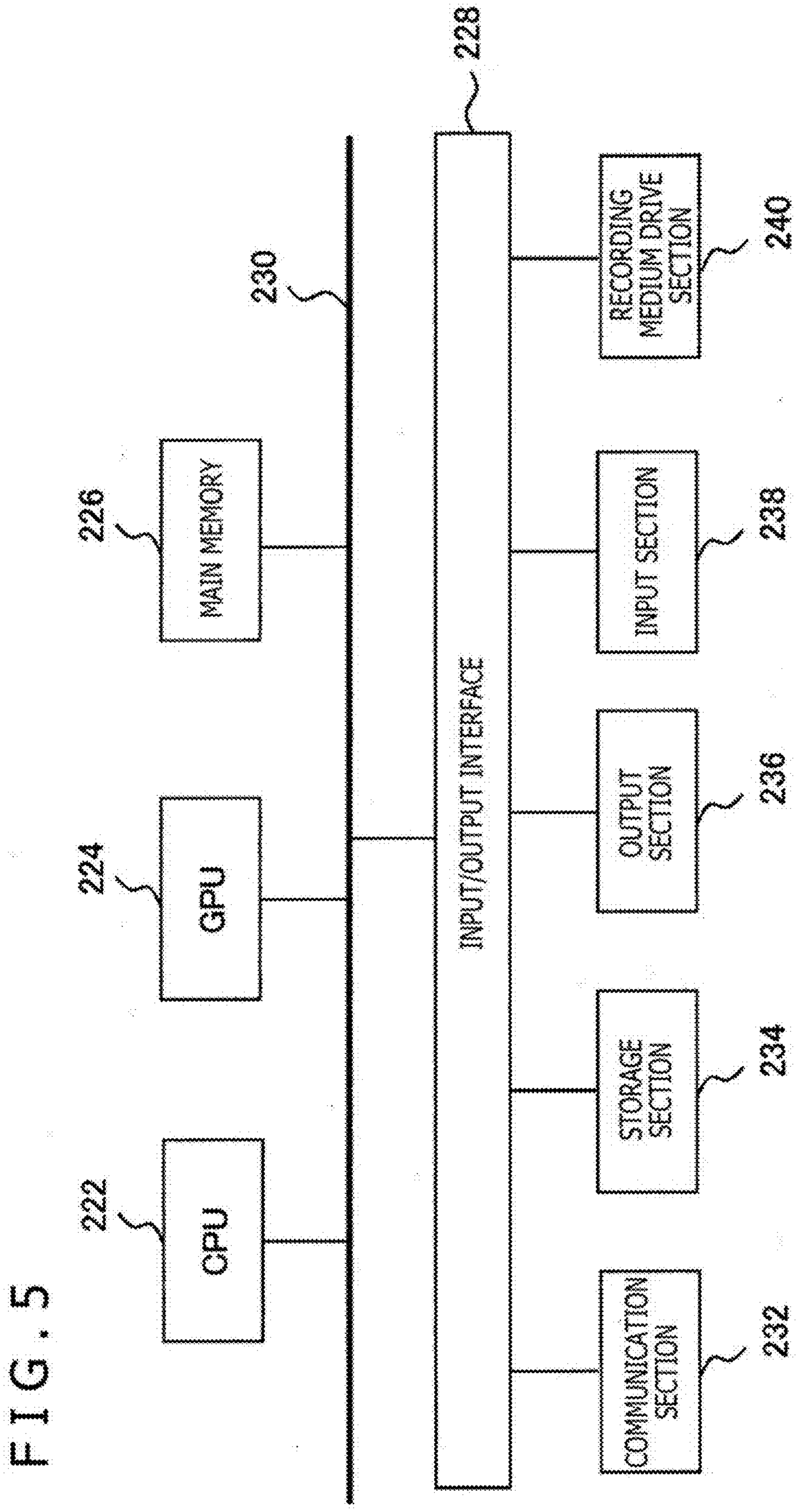

228
230
RECORDING MEDIUM DRIVE SECTION
240
MAIN MEMORY
226
GPU
224
INPUT/OUTPUT INTERFACE
INPUT SECTION
238
OUTPUT SECTION
236
200
STORAGE SECTION
234
CPU
222
COMMUNICATION SECTION
232

FIG. 5

FIG. 6

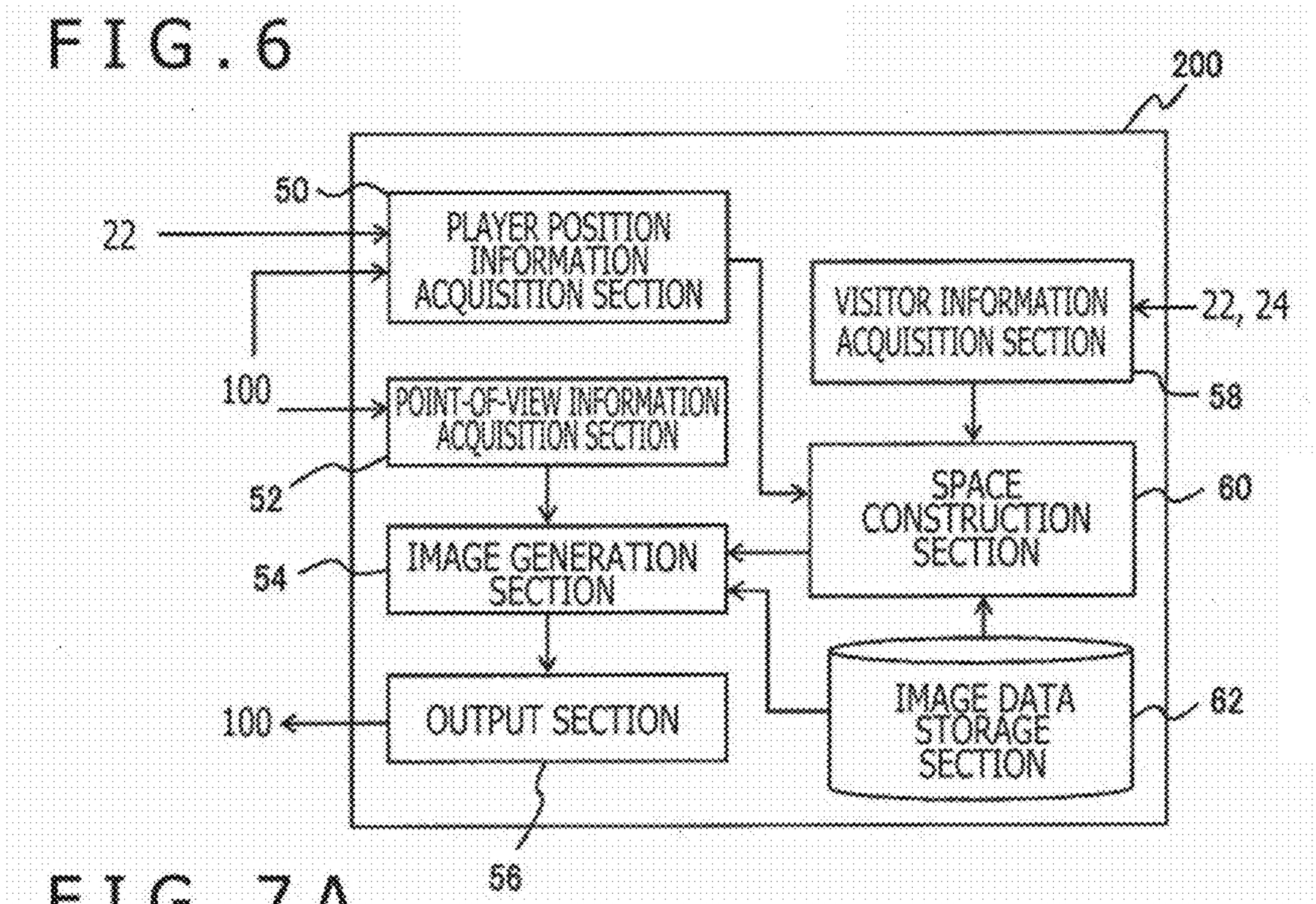


FIG. 7A

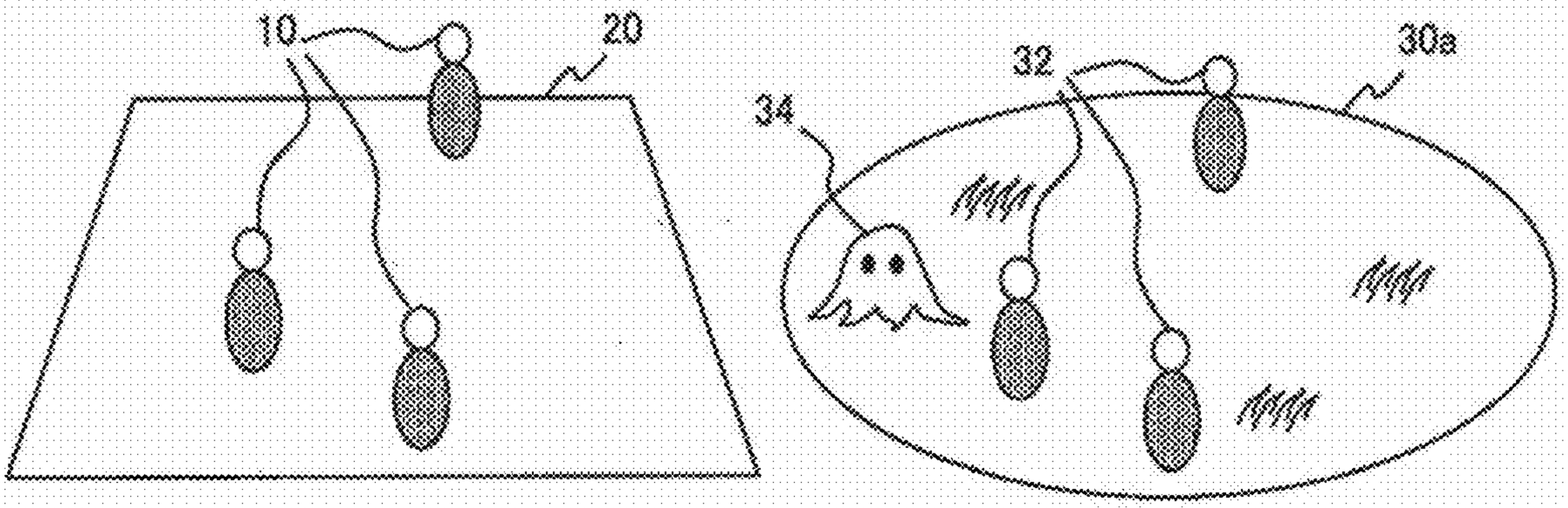


FIG. 7B

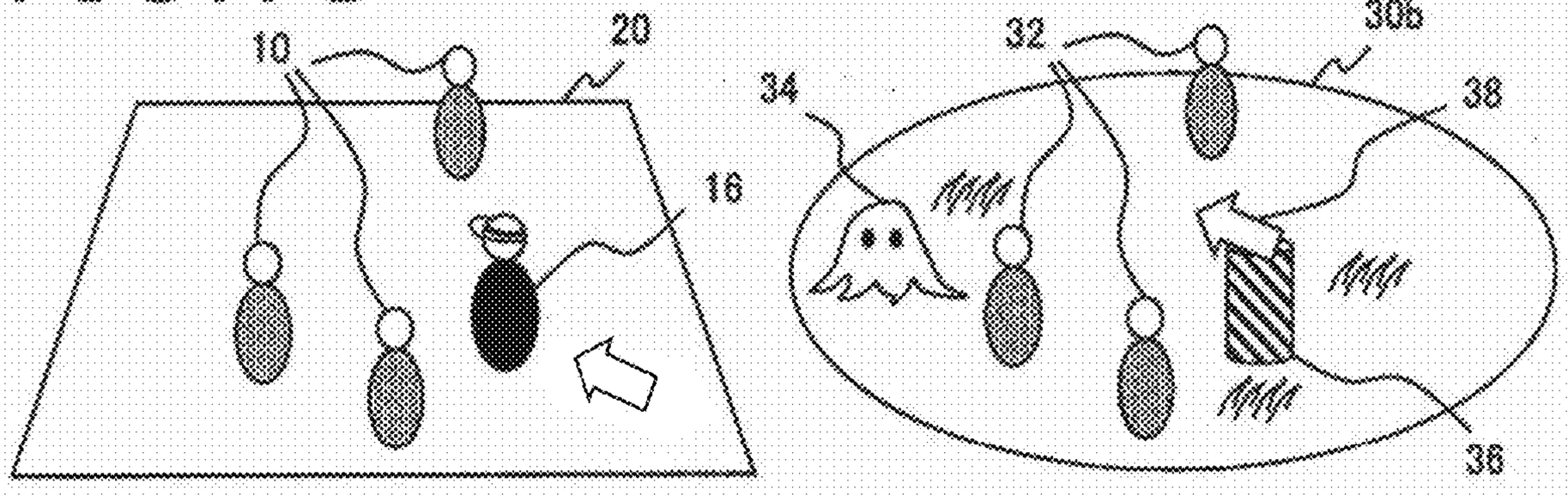


FIG. 8A

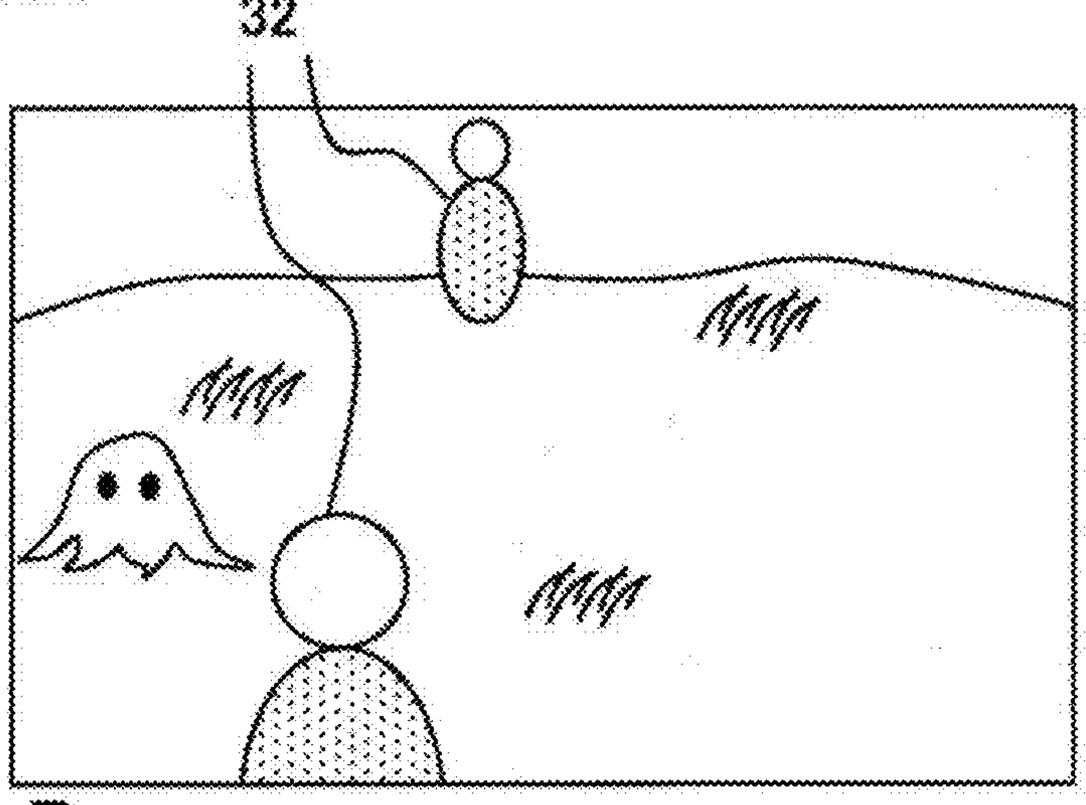


FIG. 8B

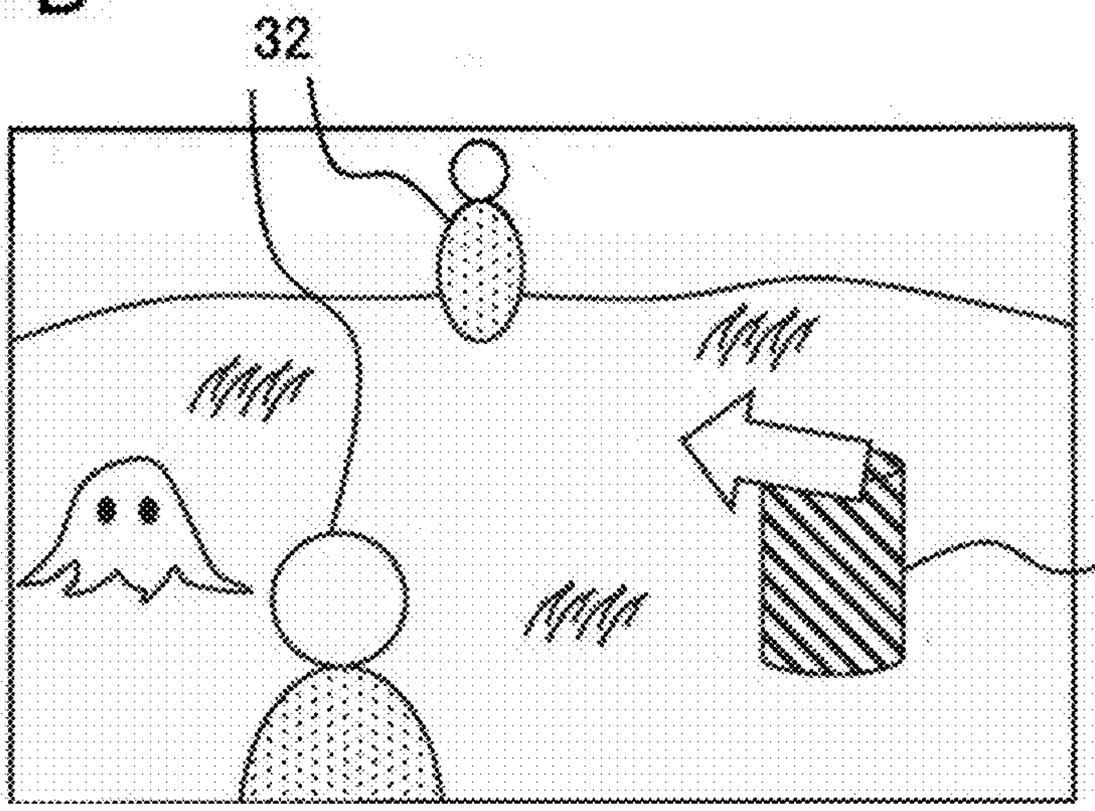


FIG. 9A

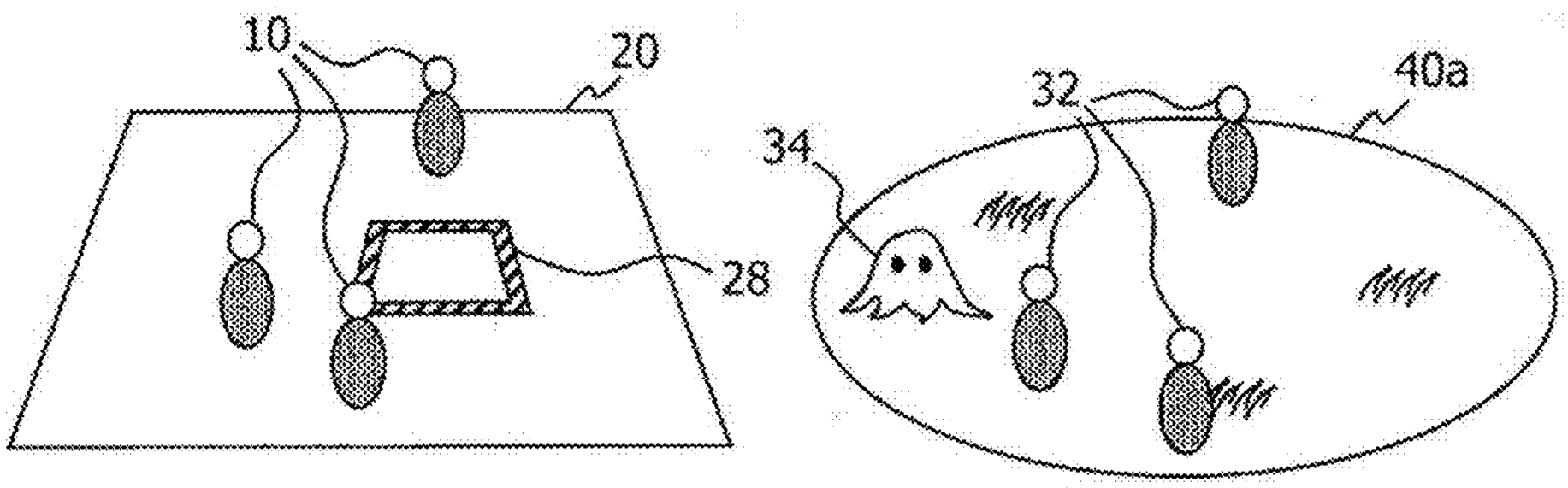


FIG. 9B

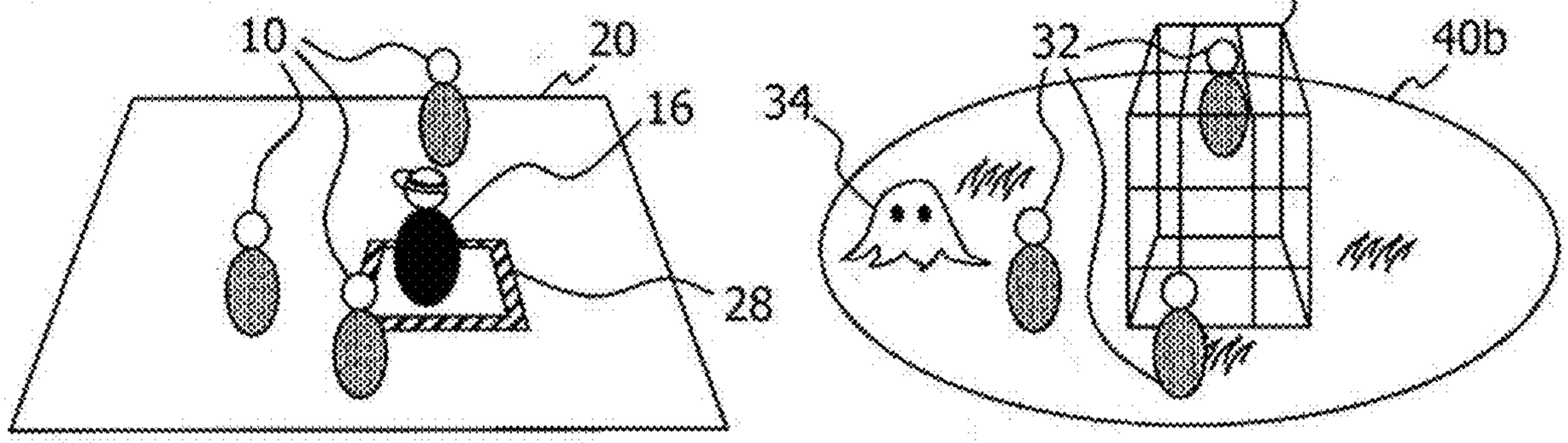


FIG. 10A

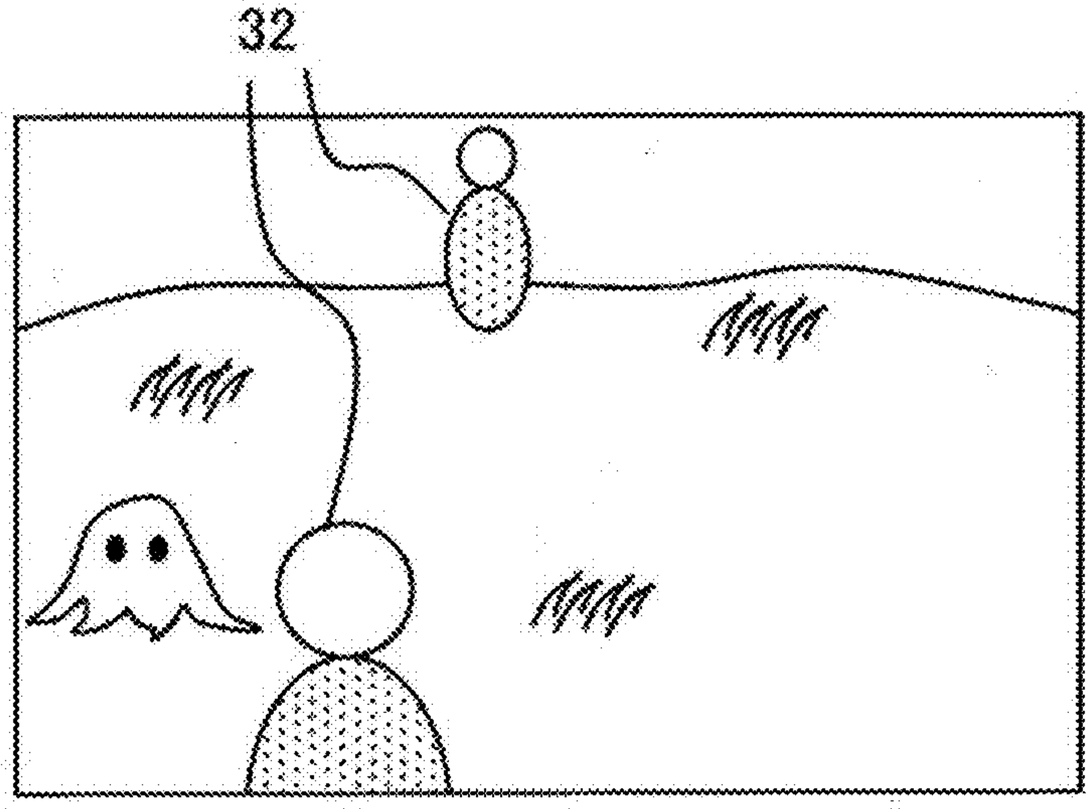


FIG. 10B

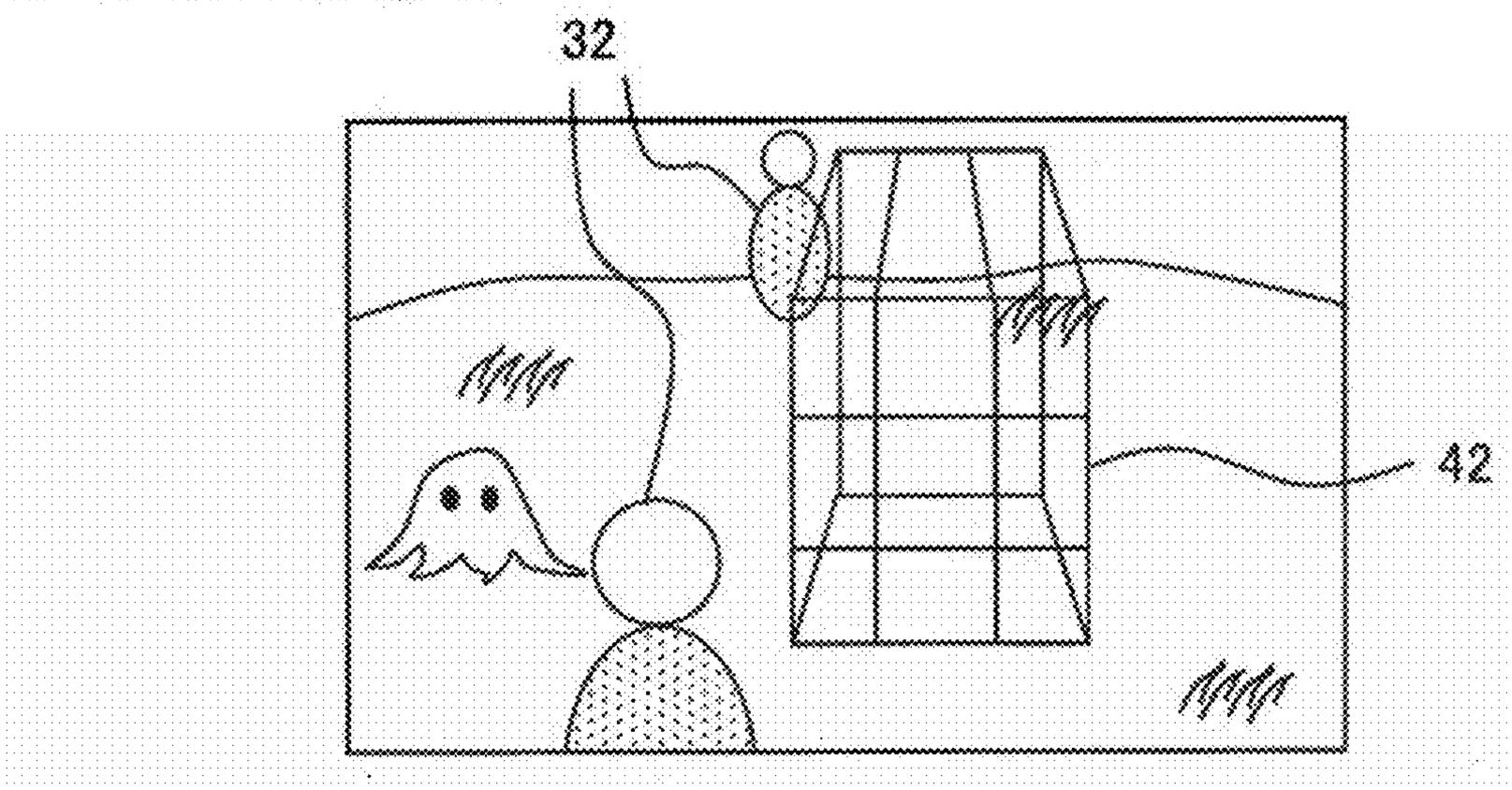


FIG. 11

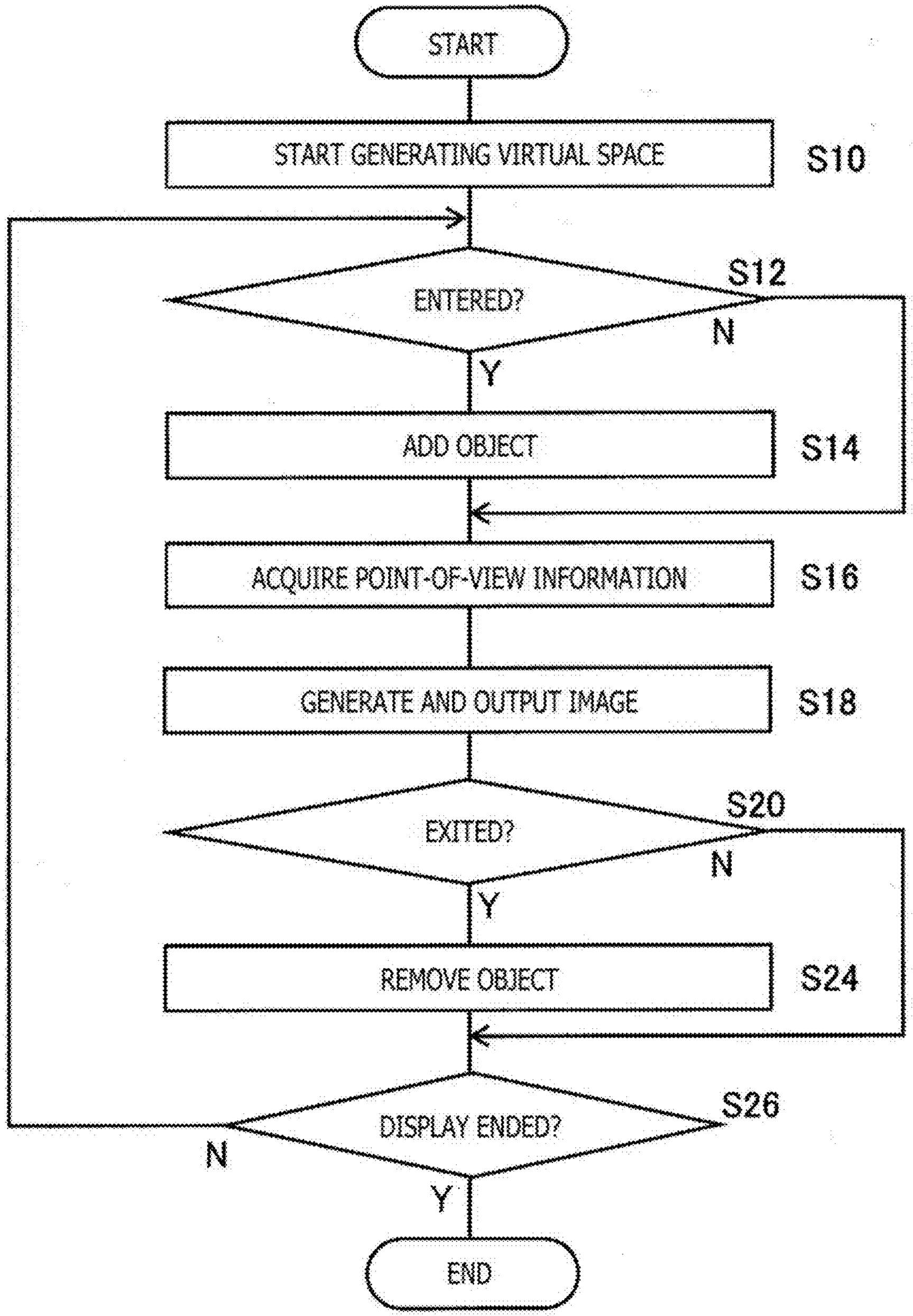

START
START GENERATING VIRTUAL SPACE
S10
ENTERED?
S12
N
Y
ADD OBJECT
S14
ACQUIRE POINT-OF-VIEW INFORMATION
S16
GENERATE AND OUTPUT IMAGE
S18
EXITED?
S20
N
Y
REMOVE OBJECT
S24
DISPLAY ENDED?
S26
N
Y
END

FIG. 12A

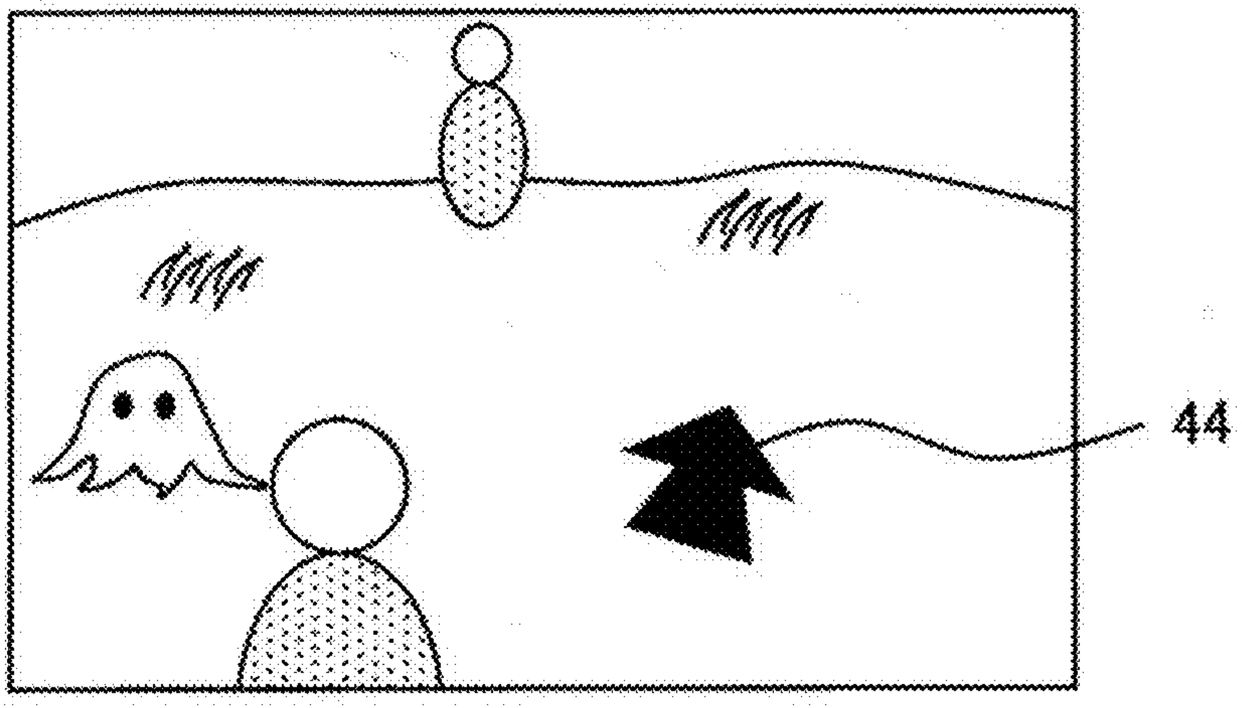


FIG. 12B

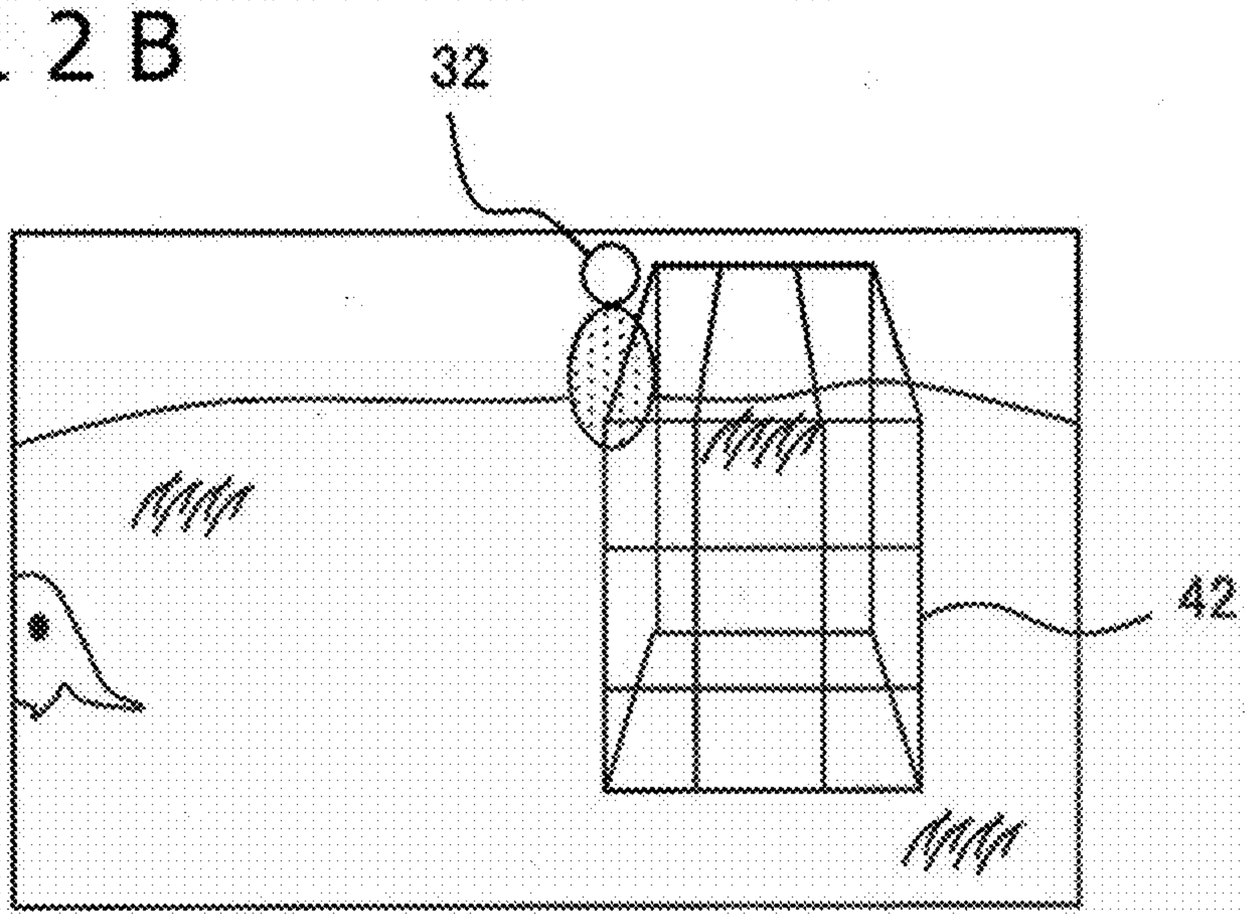


IMAGE GENERATION DEVICE, IMAGE DISPLAY SYSTEM, AND INFORMATION PRESENTATION METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. application Ser. No. 18/210,518, filed on Jun. 15, 2023, which is a continuation of U.S. application Ser. No. 17/879,271, filed on Aug. 2, 2022 (now U.S. Pat. No. 11,714,281), which is a continuation of U.S. application Ser. No. 16/843,186, filed on Apr. 8, 2020 (now U.S. Pat. No. 11,460,697), which claims the benefit of Japanese Priority Patent Application JP 2019-082184 filed Apr. 23, 2019, the entire contents of each are incorporated herein by reference.

BACKGROUND

[0002] The present disclosure relates to an image generation device configured to generate an image to be displayed on a head-mounted display, to an image display system, and to an information presentation method employed thereby.

[0003] Image display systems for watching a target space from a freely-selected point of view are widely used. For example, image display systems are developed to display panoramic video in accordance with a gaze direction of a user wearing a head-mounted display and rotating a user's head. Using a head-mounted display makes it possible to enhance the sense of immersion into video and improve the operability of applications such as games. Further, some attractions are implemented for practical applications in order to allow a user wearing a head-mounted display to experience free-roam virtual reality, which enables the user to virtually walk around in a space displayed as a video image when the user physically moves.

SUMMARY

[0004] When a user wears a non-transmissive head-mounted display, which blocks all outside light, it is obvious that the user is unable to experience the state of the outside world. When, for example, a free-roam attraction is used, it is possible to recognize initially existing items and other players in a play area due to virtual world settings. However, it is difficult to recognize an unexpected situation such as equipment failure in the play area or poor player health. If, for example, a staff member enters the play area in an attempt to cope with such an unexpected situation, the staff member becomes an obstacle to increase the level of danger.

[0005] The present disclosure has been made in view of the above circumstances, and it is desirable to provide a technology for increasing the level of safety during a movement of a user wearing a head-mounted display.

[0006] According to an embodiment of the present disclosure, there is provided an image generation device including: a space construction section that constructs a virtual world to be displayed on a head-mounted display; an image generation section that generates, based on a position and a posture of a head of a player wearing the head-mounted display, a display image representing the virtual world in a field of view corresponding to a point of view of the player, and causes the head-mounted display to display the generated display image; and a visitor information acquisition section that acquires information regarding presence of a visitor without a head-mounted display in a space where the player is able to move. While the visitor is present, the space construction section displays an object indicating the presence of the visitor at a corresponding position in the virtual world.

[0007] According to another embodiment of the present disclosure, there is provided an image display system including an image generation device, a head-mounted display, and a sensor. The image generation device includes: a space construction section that constructs a virtual world to be displayed on the head-mounted display; an image generation section that generates, based on a position and a posture of a head of a player wearing the head-mounted display, a display image representing the virtual world in a field of view corresponding to a point of view of the player, and causes the head-mounted display to display the generated display image; and a visitor information acquisition section that acquires information regarding presence of a visitor without a head-mounted display in a space where the player is able to move. While the visitor is present, the space construction section displays an object indicating the presence of the visitor at a corresponding position in the virtual world. The head-mounted display displays an image outputted from the image generation device. The sensor detects the visitor and transmits data on the visitor to the image generation device.

[0008] According to a further embodiment of the present disclosure, there is provided an image display system including an image generation device, a head-mounted display, and an input device. The image generation device includes: a space construction section that constructs a virtual world to be displayed on a head-mounted display; an image generation section that generates, based on a position and a posture of a head of a player wearing the head-mounted display, a display image representing the virtual world in a field of view corresponding to a point of view of the player, and causes the head-mounted display to display the generated display image; and a visitor information acquisition section that acquires information regarding presence of a visitor without a head-mounted display in a space where the player is able to move. While the visitor is present, the space construction section displays an object indicating the presence of the visitor at a corresponding position in the virtual world. The visitor information acquisition section detects the visitor's entry into and exit from a stay area preset in the space. While the visitor is present in the stay area, the space construction section displays an object representing a region corresponding to the stay area as the object indicating the presence of the visitor. The head-mounted display displays an image outputted from the image generation device. The input device inputs an operation indicative of the visitor's entry into and exit from the stay area, and transmits information regarding the visitor's entry into and exit from the stay area to the image generation device.

[0009] According to a yet further embodiment of the present disclosure, there is provided an information presentation method of an image generation device, including:

constructing a virtual world to be displayed on a head-mounted display; generating, based on a position and a posture of a head of a player wearing the head-mounted display, a display image representing the virtual world in a field of view corresponding to a point of view of the player, and causing the head-mounted display to display the generated display image; acquiring information regarding pres-

ence of a visitor without a head-mounted display in a space where the player is able to move; and displaying an object indicating the presence of the visitor at a corresponding position in the virtual world while the visitor is present.

[0010] Any combinations of the foregoing constituent elements and any conversions of expressions of the embodiments of the present disclosure, for example, between methods, devices, systems, computer programs, data structures, and recording media are also valid modes of the present disclosure.

[0011] According to the embodiments of the present disclosure, it is possible to increase the level of safety during a movement of a user wearing a head-mounted display.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is an example external view of a head-mounted display according to an embodiment of the present disclosure;

[0013] FIG. **2** is a diagram illustrating a configuration of a basic system according to the embodiment;

[0014] FIG. **3** is a diagram illustrating an example of an image world that is to be displayed on the head-mounted display by an image generation device in the embodiment;

[0015] FIG. **4** is a schematic diagram illustrating a play area in a free-roam exhibit to which the embodiment is applicable;

[0016] FIG. **5** is a diagram illustrating an internal circuit configuration of the image generation device according to the embodiment;

[0017] FIG. **6** is a diagram illustrating a configuration of functional blocks of the image generation device in the embodiment;

[0018] FIGS. **7**A and **7**B are diagrams illustrating an example of change that a space construction section in the embodiment applies to a virtual world in accordance with the presence of a visitor;

[0019] FIGS. **8**A and **8**B are diagrams illustrating examples of display images that represent the virtual world depicted in FIGS. **7**A and **7**B in the field of view of a player with an image generation section;

[0020] FIGS. **9**A and **9**B are diagrams illustrating another example of change that the space construction section in the embodiment applies to a virtual world in accordance with the presence of a visitor;

[0021] FIGS. **10**A and **10**B are diagrams illustrating examples of display images that represent the virtual world depicted in FIGS. **9**A and **9**B in the field of view of a player with the image generation section;

[0022] FIG. **11** is a flowchart illustrating processing that is performed by the image generation device according to the embodiment in order to generate a display image and display the generated display image on the head-mounted display; and

[0023] FIGS. **12**A and **12**B are diagrams illustrating examples of display images that the image generation section generates in a case where a stay area set in accordance with the embodiment is used as a player's shelter.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0024] FIG. **1** illustrates an example external view of a head-mounted display **100** according to an embodiment of the present disclosure. The head-mounted display **100** includes a main body section **110**, a forehead contact section **120**, and a temporal region contact section **130**. The head-mounted display **100** is a display device that is worn on the head of a user to allow the user to watch, for example, still images and video images displayed on a display and listen to, for example, sound and music outputted from headphones. A motion sensor built in or externally attached to the head-mounted display **100** is able to make measurements to obtain posture information such as a rotation angle and tilt of the head of the user wearing the head-mounted display **100**. Therefore, changing the field of view of a display image in accordance with a motion of the user's head causes the user to feel like as if the user is in an image world.

[0025] However, the shape and structure of the head-mounted display according to the present embodiment of the present disclosure are not limited to those depicted in FIG. **1**. For example, a camera may be attached to a front surface of the head-mounted display **100** in order to capture an image of a real space as viewed from a user's face. In such a case, analyzing the captured image makes it possible to acquire an orientation of the user's face and a position of the user's head and determine a position of a real item existing ahead. The captured image can also be used as the display image.

[0026] FIG. **2** is a diagram illustrating a configuration of a basic system according to the present embodiment. The head-mounted display **100** is connected to an image generation device **200** through an interface **205** that is to be connected to a peripheral such as a wireless communication or a universal serial bus (USB) device. The image generation device **200** may be further connected to a server through a network. In such a case, the server may supply, to the image generation device **200**, an online application such as a game in which a plurality of users can participate through the network.

[0027] The image generation device **200** determines a position of a virtual point of view and a direction of a gaze with respect to the display image in accordance with aa head position and a posture of the user wearing the head-mounted display **100**, generates the display image so as to provide a corresponding field of view, and outputs the generated display image to the head-mounted display **100**. As far as the image generation device **200** performs the above operations, it may display images for any appropriate purposes. For example, the image generation device **200** may generate a display image representing a virtual world that functions as a stage of an electronic game while it progresses, or display still images and video images for appreciation purposes.

[0028] Displaying an omnidirectional (360-degree) image so as to cover a wide angular range centered on a virtual point of view gives a sense of immersion into the image world. The image generation device **200** may be a separate device connected to the head-mounted display **100** through the interface **205** as depicted in FIG. **2** or may be incorporated integrally into the head-mounted display **100**.

[0029] FIG. **3** is a diagram illustrating an example of the image world that is to be displayed on the head-mounted display **100** by the image generation device **200** in the present embodiment. This example represents a state where a user **12** is in a room that is a virtual world. Objects, such as walls, a floor, a window, a table, and items on the table, are disposed in a world coordinate system defining the virtual world, as depicted in FIG. **3**. The image generation device **200** defines a view screen **14** in accordance with the

position of the point of view of the user **12** and the gaze direction of the user **12** in the world coordinate system, and draws the display image by projecting images of the objects onto the view screen **14**.

[0030] When the position of the point of view of the user **12** and the gaze direction of the user **12** (hereinafter these may be comprehensively referred to as the "point of view") are acquired at a predetermined rate and a position and an orientation of the view screen **14** are changed accordingly, images can be displayed in a field of view corresponding to the user's point of view. When stereo images having parallax are generated and displayed in front of the left and right eyes of the user **12** by using the head-mounted display **100**, a virtual space can also be viewed three-dimensionally. This enables the user **12** to experience virtual reality as if the user **12** is immersed in a room in a display world. The illustrated example assumes that a virtual world based on computer graphics is regarded as a display target. However, the display target may be an image that is obtained by combining computer graphics with a captured image of a real world such as a panoramic photograph.

[0031] The above-described technology enables the user **12** to freely walk around in a virtual world. When, for example, a position and a posture of another user existing in the same space as the user **12** are acquired to dispose an object representing an avatar of the other user in a virtual space, the user **12** visually recognizes the other user as a part of the virtual world. This scheme is used to actually utilize a free-roam multiplayer virtual experience attraction. The free-roam multiplayer virtual experience attraction (hereinafter referred to as the "free-roam exhibit") allows a plurality of players to fight and explore together in a virtual space.

[0032] FIG. **4** schematically illustrates a play area in the free-roam exhibit to which the embodiment is applicable. A play area **20** is illustrated so as to overlook a real space where the free-roam exhibit is presented. Players **10***a* to **10***d* wearing head-mounted displays **100***a* to **100***d*, respectively, exist in the play area **20**. However, the number of players is not limited. The image generation device **200** constructs a virtual world as depicted in FIG. **3**, and causes the head-mounted displays **100***a* to **100***d* worn by the players **10***a* to **10***d* to display the virtual world in a field of view corresponding to the point of view of each player.

[0033] The position and posture of each of the players **10***a* to **10***d* are acquired, for example, by obtaining values measured by motion sensors built in the head-mounted displays **100***a* to **100***d*, acquiring images captured by cameras included in the head-mounted displays **100***a* to **100***d*, and analyzing the measured values and captured images. Information obtained in this manner can also be used for constructing a virtual world. More specifically, respective objects indicating the movement of the players **10***a* to **10***d* are disposed in a virtual world in order to let the players recognize the presence and movement of the other players.

[0034] Basically, in the above-described free-roam exhibit, persons other than the players **10***a* to **10***d* are not expected to enter the play area. However, it is quite likely that a staff member or a person other than the players is compelled to enter the play area in an attempt to cope with various severities of an unexpected situation such as equipment failure, abnormal physical conditions or injuries of the players, and the loss of personal belongings of the players. In such a situation, the players **10***a* to **10***d* viewing only a virtual world including the other players feel the presence of an invisible item and thus become distracted from careful watching or cause an increased risk of collision. Further, it is not practical to interrupt all plays for safety's sake each time a minor incident occurs.

[0035] In view of the above circumstances, the present embodiment separately includes a mechanism for detecting visitors other than the players, and causes images viewed by the players **10***a* to **10***d* to reflect the presence of such a visitor. A person who is not a player but enters the play area is hereinafter referred to as a "visitor." The visitor is a person who does not wear the head-mounted display **100**, that is, a person who sees a real space. The visitor is not to be tracked in an ordinary free-roam system for tracking the position and posture of a player. As far as the visitor is such a person, the purpose of the visitor's entry into the play area and the attribute of the visitor are not specifically limited.

[0036] In order to implement the above features, an image display system according to the present embodiment incorporates a sensor **22** and an input device **24** in addition to the image generation device **200** and the head-mounted displays **100***a* to **100***d*. The sensor **22** tracks a visitor **16**. The input device **24** inputs an operation that is performed to reflect the presence of the visitor **16** in a display image. For example, the visitor **16** wears a marker and a device **26** for generating an ultrasonic wave or light having a predetermined wavelength band, and the sensor **22** tracks the presence and position of the visitor **16** by detecting the ultrasonic wave or the light having the predetermined wavelength band.

[0037] Based on the result of such tracking, the image generation device **200** disposes an object representing the visitor **16** at a corresponding position in a virtual world viewed by the players **10***a* to **10***d*. Obviously, the object in the virtual world is moved while the visitor **16** is moving. When rules are established to define a position at which the visitor **16** wears the device **26**, such as a forward position (a position toward which the visitor faces) of the visitor's head or higher than the visitor's head, or a front surface of the visitor's body, the direction in which the visitor **16** moves can be predicted based on the orientation of the face and body of the visitor **16**.

[0038] A headgear with the device **26** attached to its front surface may be created and worn by the visitor **16** entering the play area. An alternative is to prepare a mounting fixture with a bar, attach the device **26** to the tip of the bar, allow the visitor **16** to wear the mounting fixture when the visitor **16** enters the play area, and fix the device **26** at a position above the head of the visitor **16**. Raising the position of the device **26** reduces the possibility of the device **26** being hidden by the visitor **16** and the players **10***a* to **10***d* and thus enables the sensor **22** to achieve stable detection.

[0039] The image generation device **200** may allow the players **10***a* to **10***d* to determine a direction of travel of the visitor **16** by labeling an object representative of the visitor **16** with the direction of travel of the visitor **16**. This enables the players **10***a* to **10***d* to intuitively sense the presence of the visitor **16** and naturally act without colliding with the visitor **16**. The shape and position of the sensor **22** are not limited to those depicted. The sensor **22** may be mounted, for example, on a ceiling to overlook the interior of a room or may be movable. Alternatively, the sensor **22** may be built in the image generation device **200**.

[0040] The input device **24** may be a common input device such as a remote controller, a game controller, a mobile terminal, a pushbutton, or a joystick. The input device **24**

inputs an operation that determines a time point at which the presence of the visitor **16** is reflected in images viewed by the players **10***a* to **10***d*. For example, a stay area **28** of the visitor **16** is clearly marked in the play area **20** in advance, and the visitor **16** entering the stay area **28** operates the input device **24** to input information indicating that the visitor **16** has entered the stay area **28**. The input device **24** then receives the inputted information and transmits the received inputted information to the image generation device **200**. The image generation device **200** then causes an object to appear in a region within a virtual world viewed by the players **10***a* to **10***d* that corresponds to the stay area **28**.

[0041] As a result, the players **10***a* to **10***d* are able to act without entering the stay area **28**. Here, the extent, the shape, and the number of the stay area **28** are not limited. For example, the stay area **28** may be, as illustrated, an island type not in contact with the end of the play area **20** or a region in a corner of the play area **20**. Alternatively, the stay area **28** may be a passage type that crosses the play area **20**. Further, the periphery of the stay area **28** is marked by a luminescent marker or by a periphery-indicating tape attached to a floor in order to let the visitor **16** understand the periphery of the stay area **28** in the real world.

[0042] The input device **24** may be operated not only by the visitor **16** but also by, for example, an administrator present outside of the play area **20**. The administrator may watch, for example, a surveillance monitor to confirm the entry of the visitor **16** into the stay area **28** and then operate the input device **24**. Further, when the visitor **16** exits the stay area **28**, the visitor **16** operates the input device **24** to input information indicative of the exit. This causes the image generation device **200** to remove an object representing the stay area **28** from the virtual world.

[0043] Introducing the sensor **22** allows the visitor **16** to freely move in the play area **20**. Meanwhile, if the place to stay is limited, the visitor **16** should avoid the players, enter the stay area **28**, and operate the input device **24**. As described above, only one of the sensor **22** and the input device **24** may be introduced in accordance with the action to be taken by the visitor **16**.

[0044] An alternative is to track a moving visitor **16** by using the sensor **22**, reflect the movement of the visitor **16** in an object serving as a visitor's avatar, detect the entry of the visitor **16** into the stay area **28** by using the sensor **22** or the input device **24**, and switch an expression to an object representing the stay area. In this case, due to the operation of only the sensor or the collaboration between the sensor **22** and the input device **24**, an object indicating the presence of the visitor is continually expressed in different forms. In any case, the image generation device **200** is wiredly or wirelessly connected to both the sensor **22** and the input device **24**, and acquires, as needed, information transmitted from both of them.

[0045] FIG. **5** illustrates an internal circuit configuration of the image generation device **200**. The image generation device **200** includes a central processing unit (CPU) **222**, a graphics processing unit (GPU) **224**, and a main memory **226**. These constituent elements are interconnected through a bus **230**. The bus **230** is further connected to an input/output interface **228**.

[0046] The input/output interface **228** is connected to a communication section **232**, a storage section **234**, an output section **236**, an input section **238**, and a recording medium drive section **240**. The communication section **232** includes USB, IEEE 1394 (IEEE: Institute of Electrical and Electronics Engineers), and other peripheral device interfaces and a wired or wireless local area network (LAN) interface. The storage section **234** is, for example, a hard disk drive or a nonvolatile memory. The output section **236** outputs data to the head-mounted display **100**. The input section **238** inputs data from the head-mounted display **100**, the sensor **22**, and the input device **24**. The recording medium drive section **240** drives a removable recording medium such as a magnetic disk, an optical disc, or a semiconductor memory.

[0047] When an operating system stored in the storage section **234** is executed, the CPU **222** exercises overall control of the image generation device **200**. Further, the CPU **222** executes various programs that are read from a removable recording medium and loaded into the main memory **226** or downloaded through the communication section **232**. The GPU **224** has a function of a geometry engine and a function of a rendering processor, performs drawing processing in accordance with a drawing command from the CPU **222**, and stores the display image in an undepicted frame buffer. The GPU **224** then converts the display image stored in the frame buffer to a video signal and outputs the video signal to the output section **236**. The main memory **226** includes a random-access memory (RAN) and stores the programs and data to be used for processing.

[0048] FIG. **6** illustrates a configuration of functional blocks of the image generation device **200** in the present embodiment. As mentioned earlier, the image generation device **200** may perform general information processing such as causing an electronic game to progress or communicating with a server. However, FIG. **6** particularly focuses on a function of controlling the display image in accordance with a visitor's entry and exit. At least some of the functions of the image generation device **200**, which are depicted in FIG. **6**, may be implemented in the head-mounted display **100**. Alternatively, at least some of the functions of the image generation device **200** may be implemented in a server that is connected to the image generation device **200** through a network.

[0049] Further, the functional blocks depicted in FIG. **6** can be implemented by hardware such as the CPU, GPU, memories, or other constituent elements depicted in FIG. **5**, or implemented by software including programs for exercising various functions such as a data input function, a data retention function, an image processing function, and a communication function, the programs being loaded from a recording medium or the like into a memory. Therefore, it will be understood by those skilled in the art that the functional blocks may be implemented by hardware alone, by software alone, or by a combination of hardware and software and are not to be limited to any of them.

[0050] The image generation device **200** includes a player position information acquisition section **50**, a point-of-view information acquisition section **52**, a visitor information acquisition section **58**, a space construction section **60**, an image generation section **54**, an image data storage section **62**, and an output section **56**. The player position information acquisition section **50** acquires information regarding the position of a player in the play area. The point-of-view information acquisition section **52** acquires information regarding the point of view of a user. The visitor information acquisition section **58** acquires information regarding the entry, exit, and position of a visitor. The space construction section **60** constructs a virtual world. The image generation

section **54** generates the display image. The image data storage section **62** stores image data to be used for generating the display image. The output section **56** outputs the display image to the head-mounted display **100**.

[0051] The player position information acquisition section **50** includes, for example, the input section **238** and the CPU **222**, which are depicted in FIG. **5**, and acquires information regarding the position of each player in the play area at a predetermined rate. The information regarding the position of each player can be obtained by successively acquiring output data from various motion sensors and cameras built in the head-mounted display **100** worn by each player as mentioned earlier and analyzing the acquired output data.

[0052] Alternatively, for example, a camera separately disposed in the play area may be used to perform image analysis in order to track the position and posture of a player wearing a luminescent marker of a predetermined color. Another alternative is to attach a device configured to generate, for example, an ultrasonic wave detectable by the sensor **22** to the body of a player. When such an alternative is used, the player position information acquisition section **50** acquires data transmitted from the sensor **22**, and determines the position and posture of the player in accordance with the acquired data.

[0053] Further, the player position information acquisition section **50** internally retains data defining a normal range of a parameter indicating the posture of a player, and detects a state where the determined posture of the player is outside the normal range. In a case where an ultrasonic wave or light from, for example, a marker worn by a player is detected in order to determine the posture of the player, it is conceivable that the result of player detection may be affected by an approaching visitor. Accordingly, the posture determined based on the result of player detection may be in an abnormal state different from an actual state.

[0054] Consequently, the player position information acquisition section **50** detects such a state, and prevents the detected state from being reflected in the posture of an object representing the player. Data indicating, for example, postures assumable at a time by a human and a range of possible movement of a human during a limited period of time is prepared as the data defining the normal range. As regards the data indicating the range of possible movement of a human during a limited period of time, the player position information acquisition section **50** determines, based on posture changes from a previous time step, whether or not the normal range is exceeded.

[0055] The point-of-view information acquisition section **52** includes, for example, the input section **238** and the CPU **222**, which are depicted in FIG. **5**, and acquires information regarding the position of each player's point of view and the gaze direction of each player at a predetermined rate. For example, the point-of-view information acquisition section **52** successively acquires output values from an acceleration sensor built in the head-mounted display **100**, and acquires the posture of a player's head in accordance with the acquired output values. The position of the player's head in a real space may be acquired by analyzing an image of a luminescent marker attached to the head-mounted display **100**, which is captured by a camera separately disposed in the play area as mentioned earlier.

[0056] Alternatively, the position and posture of the head of a player may be acquired by analyzing an image captured by a camera provided for the head-mounted display **100** through the use, for example, of a simultaneous localization and mapping (SLAM) technology. When the position and posture of the player's head are acquired, it is possible to roughly determine the position of the player's point of view and the gaze direction of the player. Further, it will be understood by those skilled in the art that the information regarding the player's point of view can be acquired by various methods. As the processing performed by the player position information acquisition section **50** is similar to the processing performed by the point-of-view information acquisition section **52**, the result of processing performed by the point-of-view information acquisition section **52** may be shared by the player position information acquisition section **50**.

[0057] The visitor information acquisition section **58** includes, for example, the input section **238** and the CPU **222**, which are depicted in FIG. **5**, and acquires information regarding the presence of a visitor other than players. More specifically, based on data transmitted from the sensor **22**, the visitor information acquisition section **58** detects the entry and exit of a visitor, and acquires the position of the visitor in the play area at a predetermined rate. In some cases, based on data transmitted from the input device **24**, the visitor information acquisition section **58** detects a visitor's entry into or exit from the stay area previously set in the play area. As mentioned earlier, the visitor information acquisition section **58** may acquire data from one of or both the sensor **22** and the input device **24**.

[0058] The space construction section **60** includes, for example, the CPU **222** depicted in FIG. **5**, and constructs the space of a virtual world to be displayed on the head-mounted display **100**. The details of the space to be constructed vary with the purpose of a free-roam exhibit. In any case, the space construction section **60** disposes an object representing a player at a virtual location to be displayed. Players in the virtual world are allowed to visually recognize each other by moving individual objects in accordance with the result of player tracking, which is acquired by the player position information acquisition section **50**. In a case where the player position information acquisition section **50** acquires the player's posture as well, the space construction section **60** changes an object's posture as well in accordance with the player's posture.

[0059] If it is detected that the calculated posture of a player, which is determined by the player position information acquisition section **50**, is outside the normal range, the space construction section **60** locks the posture of the corresponding object in an immediately preceding state. In this instance, the space construction section **60** changes a mode of the locked object, for example, by making the locked object semitransparent or changing the color of the locked object. The display image then causes the other players to understand that temporary measures are taken. When it is detected that the calculated posture has returned to the normal range, the space construction section **60** restores the corresponding object to its previous mode and causes the prevailing posture to be reflected in the corresponding object.

[0060] Further, while a visitor is in the play area, the space construction section **60** displays an object indicating the presence of the visitor at a corresponding position in the virtual world. More specifically, when the position of the visitor is being tracked by the sensor **22**, the space construction section **60** displays an object that moves in accordance

with the movement of the visitor. In such an instance, the space construction section **60** may determine an orientation of the face and body of the visitor in accordance with the result of tracking by the sensor **22**, and label the corresponding object with a direction of travel inferred from the determined orientation. For example, the object may be affixed with a pictorial figure indicating the direction of travel. As an alternative, a face of the object may be created to indicate the direction of travel. The space construction section **60** may predict an immediately succeeding direction of travel in accordance with a record of previous movements of the visitor, and causes the result of prediction to be reflected in the object.

[0061] Alternatively, in a case where a visitor's entry into and exit from the stay area are detected based on data from the input device **24** or the sensor **22**, the space construction section **60** displays an object representing the stay area while the visitor is in the stay area. The image data storage section **62** is implemented, for example, by the main memory **226** depicted in FIG. **5**, and stores three-dimensional models, for example, of the virtual world to be constructed by the space construction section **60**, player objects, and visitor objects.

[0062] The image generation section **54** is implemented, for example, by the CPU **222**, the GPU **224**, and the main memory **226**, which are depicted in FIG. **5**, and generates a display image representative of a virtual world at a predetermined rate in a field of view corresponding to the point of view of each player, which is acquired by the point-of-view information acquisition section **52**. Stated differently, the image generation section **54** sets a view screen so as to match the point of view of each player, and presents a display image by projecting the virtual world constructed by the space construction section **60** onto the view screen. In a case where stereo images are used to provide a stereoscopic vision, the image generation section **54** generates left- and right-eye images by setting the view screen for each of the left and right eyes.

[0063] The output section **56** includes, for example, the CPU **222**, the main memory **226**, and the output section **236**, which are depicted in FIG. **5**, and transmits display image data generated by the image generation section **54** to the head-mounted display **100** at a predetermined rate. In a case where the image generation section **54** generates stereo images to provide a stereoscopic vision, the output section **56** generates a display image by joining the generated stereo images as left and right stereo images, and outputs the generated display image. In a case where the head-mounted display **100** is configured for watching a display image through a lens, the output section **56** corrects the display image in consideration of distortion caused by the lens.

[0064] FIGS. **7**A and **7**B illustrate an example of change that the space construction section **60** applies to a virtual world in accordance with the presence of a visitor. Depicted in FIG. **7**A are a real space in which no visitor is in a play area and a virtual world corresponding to the real space. Players **10** exist in the play area **20**, which is the real space. Meanwhile, in a virtual world **30***a* constructed by the space construction section **60**, objects **32** representing the respective players **10** are disposed at positions corresponding to those of the players **10**.

[0065] The space construction section **60** moves the objects **32** in accordance with the movement of the players **10**. For example, an object **34** representing a character other than the players **10** is disposed as needed in the virtual world **30***a*. If, in such a situation, a visitor **16** enters the play area **20** as depicted in FIG. **7**B, the movement of the visitor **16** is tracked by the sensor **22**. The space construction section **60** then causes an object **36** to appear in a virtual world **30***b*. The object **36** moves in accordance with the movement of the visitor **16**.

[0066] When a device configured to generate, for example, an ultrasonic wave is attached to the front surface of the body or head of the visitor **16**, it is possible to infer the direction of travel of the visitor **16**. Therefore, the space construction section **60** attaches a direction object **38** indicative of the direction of travel to the object **36** representing the visitor. As mentioned earlier, the direction of travel may be inferred from the track of movement. Further, in the present example, the direction object **38** is shaped like an arrow indicative of the direction of travel. However, the shape of the direction object **38** is not specifically limited as far as the players are able to recognize the direction. Furthermore, the shapes of the objects representing the visitor or players are not specifically limited. When the object **36** representing the visitor is shaped like a human, the direction of travel of the visitor may be indicated by the orientation of the face of the visitor.

[0067] FIGS. **8**A and **8**B illustrate examples of display images that represent the virtual world depicted in FIGS. **7**A and **7**B in the field of view of a player with the image generation section **54**. Depicted in FIG. **8**A is a state where no visitor exists in the play area as depicted in FIG. **7**A, and the objects **32** representing the other players are visible in the virtual world. Depicted in FIG. **8**B is a state where a visitor exists in the play area as depicted in FIG. **7**B, and the objects **32** representing the other players and the object **36** representing the visitor are both visible. When the above-described images are displayed, the players are able to intuitively sense the direction in which the visitor is present and the direction of travel of the visitor, and thus do not feel uncomfortable with or collide with an invisible presence. Further, the sense of immersion will not be reduced because such an invisible presence is recognized as a part of the virtual world.

[0068] FIGS. **9**A and **9**B illustrate another example of change that the space construction section **60** applies to a virtual world in accordance with the presence of a visitor. Depicted in FIG. **9**A are a real space in which no visitor is in the play area and a virtual world corresponding to the real space. Players **10** exist in the play area **20**, which is a real space. In the play area **20** depicted in the present example, the stay area **28** of a visitor is labeled, for example, with a marker or a tape. Meanwhile, in a virtual world **40***a* constructed by the space construction section **60**, objects **32** representing the respective players **10** and an object **34** representing a character other than the players are disposed, as is the case with FIG. **7**A.

[0069] In the above case, too, the space construction section **60** moves the objects **32** in accordance with the movement of the players **10**. However, in a state where no visitor exists as illustrated in FIG. **9**A, the stay area **28** does not exist in the virtual world **40***a*, either. If, in such a situation, the visitor **16** enters the stay area **28** as depicted in FIG. **9**B and is detected due, for instance, to an operation of the input device **24**, the space construction section **60** causes an object **42** representing a region corresponding to the stay area **28** to appear in a virtual world **40***b*. In the illustrated example, the object **42** is shaped like a fence surrounding the

region. However, the shape of the object **42** is not specifically limited as far as the players are able to recognize that they are not allowed to enter the region.

[0070] FIGS. **10**A and **10**B illustrate examples of display images that represent the virtual world depicted in FIGS. **9**A and **9**B in the field of view of a player with the image generation section **54**. Depicted in FIG. **10**A is a state where no visitor is in the play area as depicted in FIG. **9**A, and the objects **32** representing the other players are visible in the virtual world. Meanwhile, the image depicted in FIG. **10**A does not permit the stay area to be visually recognized. Even if a visitor is present in the play area, the same image may be displayed as far as the visitor is not in the stay area. Alternatively, based on the result of tracking by the sensor **22**, the object **36** moving in accordance with the movement of the visitor may be displayed as depicted in FIG. **8**B.

[0071] Depicted in FIG. **10**B is a state where a visitor is in the stay area as depicted in FIG. **9**B, and the objects **32** representing the other players and the object **42** representing a region corresponding to the stay area are both visible. When the above-described images are displayed, the players are able to intuitively sense a region that the players are not allowed to enter, and thus do not feel uncomfortable with or collide with an invisible presence. Further, in this case, too, the sense of immersion will not be reduced because such an invisible presence is recognized as a part of the virtual world.

[0072] An operation of the image generation device **200**, which is implemented by the above-described configuration, will now be described. FIG. **11** is a flowchart illustrating processing that is performed by the image generation device **200** according to the present embodiment in order to generate a display image and display the generated display image on the head-mounted display **100**. The processing depicted in the flowchart starts in a state where a player wears the head-mounted display **100** and the image generation device **200** establishes communication with the head-mounted display **100** and the sensor **22** or with the input device **24**. In this state, the head-mounted display **100** transmits, for example, the values measured by the motion sensors to the image generation device **200**.

[0073] The space construction section **60** then starts generating a virtual world that is to be displayed (step S**10**). In a case where there are a plurality of players, objects representing the players are included in the virtual world. Subsequently, the space construction section **60** performs a process of moving the objects in accordance with the positions of the players while the processing steps in FIG. **11** are performed. The objects may be moved in accordance with the movement of the players. In this instance, when the posture of a player subjected to a tracking process is outside the normal range, the space construction section **60** applies image effects, for example, by locking the posture of a corresponding object in an immediately preceding state and making the locked object semitransparent. When it is determined that the posture has returned to the normal range, the space construction section **60** restores the object to its previous mode.

[0074] If no visitor entering the play area or the stay area is detected ("N" at step S**12**), the point-of-view information acquisition section **52** acquires the point-of-view information regarding each player (step S**16**), and the image generation section **54** generates a display image representing a virtual world in a field of view corresponding to the point of view of each player and thus causes the output section **56** to output data on the display image (step S**18**). When the outputted data is displayed on the head-mounted display **100** of each player, the virtual world depicted, for example, in FIG. **8**A or FIG. **10**A is visually recognized.

[0075] As far as no visitor is present ("N" at step S**20**) and it is not necessary to end an image display operation ("N" at step S**26**), the display image from the point of view of each player is successively generated and outputted ("N" at step S**12**, step S**16**, and step S**18**). If a visitor entering the play area or the stay area is detected ("Y" at step S**12**), the space construction section **60** adds an object indicating the presence of the detected visitor to the virtual world (step S**14**).

[0076] More specifically, in a case where the position of a visitor is being tracked, an object indicating the movement of the visitor is added to the virtual world. When the entry of the visitor into the stay area is detected, an object representing a region corresponding to the stay area is added. When, in this state, the point-of-view information acquisition section **52** acquires the point-of-view information regarding each player (step S**16**) and the image generation section **54** generates a display image corresponding to the acquired point-of-view information, the output section **56** outputs data on the generated display image (step S**18**).

[0077] When the generated display image is displayed on the head-mounted display **100** of each player, the presence of the visitor is visually recognized as depicted in FIG. **8**B and FIG. **10**B. As far as the visitor does not exit ("N" at step S**20**) and it is not necessary to end the image display operation ("N" at step S**26**), the display image from the point of view of each player is successively generated and outputted ("N" at step S**12**, step S**16**, and step S**18**). However, if a new visitor enters the play area or enters another stay area ("Y" at step S**12**), an object indicating the presence of the new visitor is further added to the virtual world (step S**14**).

[0078] Meanwhile, if it is detected that a visitor in the play area or the stay area has exited ("Y" at step **20**), the space construction section **60** removes an object indicating the presence of the visitor from the virtual world (step S**24**). As far as it is not necessary to end the image display operation ("N" at step S**26**), steps S**12** to S**24** are repeated by branching as needed between relevant steps. When it becomes necessary to end the image display operation ("Y" at step S**26**), the whole processing ends.

[0079] The stay area in the present embodiment may be used not only as a visitor's shelter but also as a player's shelter. More specifically, a player in a poor physical condition or feeling tired in the middle of a play may use the stay area as a shelter where the player is not interfered with by another player. As mentioned earlier, the stay area labeled within the play area is not visually recognized by the players under normal conditions. Therefore, the space construction section **60** or the image generation section **54** operates in such a manner that a pictorial figure indicating a direction toward the stay area as viewed from a relevant player is depicted in the virtual world or in the display image.

[0080] FIGS. **12**A and **12**B illustrate examples of display images that the image generation section **54** generates in a case where the stay area set in accordance with the embodiment is used as a player's shelter. Depicted in FIG. **12**A is an image displayed on the head-mounted display **100** of a player who wants to take shelter in the stay area. When a player is placed in a situation where the player wants to take

shelter, the player indicates such a situation by performing an input operation with an undepicted input device possessed by the player or with the head-mounted display **100** that moves based on the motion of the head of the player. Accordingly, the image generation section **54** operates in such a manner that a pictorial FIG. **44** guiding the player to the stay area appears within the image to be displayed on the head-mounted display **100** of the player.

[0081] In the present example, the pictorial FIG. **44** is shaped like an arrow indicating a direction toward the stay area. However, the shape of the pictorial FIG. **44** is not specifically limited as far as the player is able to recognize the direction toward the stay area. The pictorial FIG. **44** may be depicted in the virtual world by the space construction section **60**, or may be superimposed on a displayed image by the image generation section **54**. The player position information acquisition section **50** detects that the player has moved in accordance with the pictorial FIG. **44** and entered the stay area. In such an instance, the space construction section **60** causes an object representing a region corresponding to the stay area to appear in the virtual world, as is the case with a visitor.

[0082] Depicted in FIG. **12**B is an image that is displayed on the head-mounted display **100** of another player in the resulting situation. In this instance, too, the object **42** representing a region corresponding to the stay area is displayed as is the case with FIG. **10**B. This enables the other player to intuitively sense a region that cannot be entered, and thus avoid interfering with a sheltered player. The image displayed on the head-mounted display **100** of the sheltered player is changed in a predetermined manner at the time point of entry into the stay area in order to notify the sheltered player of the entry into the stay area.

[0083] Subsequently, if, for example, a visitor enters, as needed, the same stay area as the sheltered player and then exits together with the sheltered player, and such a situation is detected by the player position information acquisition section **50** or the visitor information acquisition section **58**, the space construction section **60** removes the object **42** so as to return to a normal state. Alternatively, when a problem encountered by the sheltered player is solved, the sheltered player is able to exit the stay area and return to a play. In such a case, too, the space construction section **60** removes the object **42** from the virtual world at a time point at which the sheltered player exits the stay area.

[0084] In a free-roam exhibit where a player uses a head-mounted display to walk around in a virtual world, the present embodiment, which has been described above, detects a person other than the player has entered a play area and causes the presence of such a detected person to be reflected in an image displayed on the head-mounted display of the player. More specifically, the present embodiment tracks the position of a visitor by attaching a sensor-detectable device to the visitor and allowing a sensor to detect the sensor-detectable device. In this case, the present embodiment causes an object representing the visitor to appear in the virtual world.

[0085] An alternative is to set a dedicated stay area in the play area and use, for example, an input device to detect, for instance, a visitor entering the dedicated stay area. In this case, the present embodiment causes an object representing a region corresponding to the dedicated stay area to appear while the visitor is present in the stay area. In either of the above cases, the present embodiment enables even a player viewing only the virtual world to intuitively sense the presence of a visitor and prevents the player from feeling uncomfortable with the intuitively sensed presence of the visitor and from colliding with the visitor.

[0086] Further, the present embodiment is able to recognize even such a sudden event as a part of the virtual world. This enables the player to continue playing without losing the sense of immersion. Furthermore, when a player having a problem during a play is guided to the stay area and an object representing the player is made to appear in a similar manner, the present embodiment enables the player to address the problem without interfering with another player. Moreover, when the result of player detection is affected by a visitor and a calculated posture is detected to be abnormal, the present embodiment prevents the calculated posture from being reflected in a corresponding object. This makes it possible to minimize the influence of the presence of a visitor on a play.

[0087] While the present disclosure has been described in conjunction with an embodiment, it will be understood by those skilled in the art that the embodiment is illustrative and not restrictive, and that the combination of constituent elements and individual processes in the embodiment may be variously modified, and further that such modifications also fall within the scope of the present disclosure.

What is claimed is:

1. An electronic device comprising:

circuitry configured to

construct a virtual space to be displayed on a head-mounted display;

generate, based on a position and a posture of a head of a player wearing the head-mounted display, a display image representing the virtual space in a field of view corresponding to a point of view of the player, and cause the head-mounted display to display the generated display image;

acquire information regarding presence of a real-world object in a real-world space where the player is located; and

cause the head-mounted display to display an object in the virtual world corresponding to the real-world object while the real-world object is present within the real-world space.

2. The electronic device of claim **1**, further comprising:

a sensor configured to detect the presence of the real-world object in the real-world space where the player is located.

3. The electronic device of claim **1**, wherein

the circuitry is configured to cause the head-mounted display to display the object at a position in the virtual world corresponding to a location of the real-world object in the real-world space.

4. The electronic device of claim **3**, wherein

the circuitry is configured to cause the head-mounted display to change the position of the object displayed in the virtual world as the real-world object moves in the real-world space.

5. The electronic device of claim **1**, wherein

the object is a graphic representation corresponding to the real-world object.

6. The electronic device of claim **2**, wherein

the circuitry is configured to determine whether the real-world object is within a predetermined distance of the head-mounted display.

7. The electronic device of claim 6, wherein
the circuitry is configured to determine that the real-world object is within the real-world space where the player is located in a case that the real-world object is less than the predetermined distance from the head-mounted display.
8. The electronic device of claim 6, wherein
the circuitry is configured to determine that the real-world object is outside the real-world space where the player is located in a case that the real-world object is more than the predetermined distance from the head-mounted display.
9. The electronic device of claim 1, wherein
the circuitry is configured to determine that the real-world object is within the real-world space where the player is located.
10. The electronic device of claim 9, wherein
the circuitry is configured to determine that the real-world object is within the real-world space where the player is located in a case that the real-world object is less than a predetermined distance from the head-mounted display.
11. The electronic device of claim 9, wherein
the circuitry is configured to determine that the real world object is within the real-world space where the player is located in a case that the real-world object is within a virtual perimeter defined within the real-world space.
12. A head mounted display, comprising:
a display;
a sensor configured to detect a real-world object; and
circuitry configured to
execute a program to construct a virtual space to be displayed by the display;
generate, based on a position and posture of a head of a player wearing the head-mounted display, a display image representing the virtual space in a field of view corresponding to a point of view of the player;
control the display to the generated display image;
acquire, based on an output of the sensor, information regarding presence of a real-world object in a real-world space surrounding the head-mounted display;
determine whether the real-world object satisfies a predetermined condition; and
control the display to display a graphical representation of the real-world object in the virtual world in a case that the real-world object satisfies the predetermined condition.
13. The head-mounted display of claim 12, wherein
the circuitry is configured to control the display to display the graphical representation of the real-world object in the virtual world at a position corresponding to a location of the real-world object in the real-world space in a case that the real-world object satisfies the predetermined condition.
14. The head-mounted display of claim 12, wherein
the predetermined condition is that the real-world object is within a predetermined distance from the head-mounted display.
15. The head-mounted display of claim 14, wherein
the circuitry is configured to control the display to not display the graphical representation of the real-world object in a case that the real-world object is greater than the predetermined distance from the head-mounted display.
16. The head-mounted display of claim 12, wherein
the predetermined condition is that the real-world object is within a virtual perimeter defined around the head-mounted display.
17. The head-mounted display of claim 16, wherein
the circuitry is configured to control the display to not display the graphical representation of the real-world object in a case that the real-world object is outside of the virtual perimeter defined around the head-mounted display.
18. A method performed by a head-mounted display, the method comprising:
executing a program to construct a virtual space to be displayed by a display;
generating, based on a position and posture of a head of a player wearing the head-mounted display, a display image representing the virtual space in a field of view corresponding to a point of view of the player;
controlling the display to the generated display image;
acquiring information regarding presence of a real-world object in a real-world space surrounding the head-mounted display;
determining that the real-world object satisfies a predetermined condition; and
controlling the display to display a graphical representation of the real-world object in the virtual world upon determining that the real-world object satisfies the predetermined condition.
19. The method of claim 18, wherein
the predetermined condition is that the real-world object is within a predetermined distance from the head-mounted display.
20. The method of claim 18, further comprising:
controlling the display to not display the graphical representation of the real-world object in the virtual world upon determining that the real-world object does not satisfy the predetermined condition.
21. A non-transitory computer readable medium including computer-program instructions, which when executed by circuitry, cause the circuitry to:
construct a virtual space to be displayed on a head-mounted display;
generate, based on a position and a posture of a head of a player wearing the head-mounted display, a display image representing the virtual space in a field of view corresponding to a point of view of the player, and cause the head-mounted display to display the generated display image;
acquire information regarding presence of a real-world object in a real-world space where the player is located; and
cause the head-mounted display to display an object in the virtual world corresponding to the real-world object while the real-world object is present within the real-world space.

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